A Technique to Control Mercury From Flue Gas: The Thief Process

Mark Freeman, Henry Pennline, Evan Granite,
Richard Hargis, and William O'Dowd

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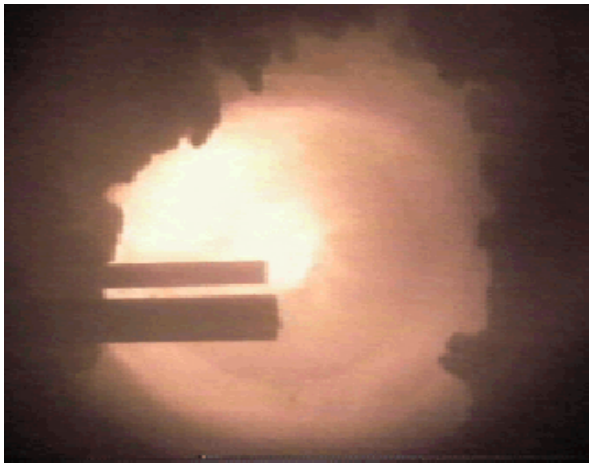
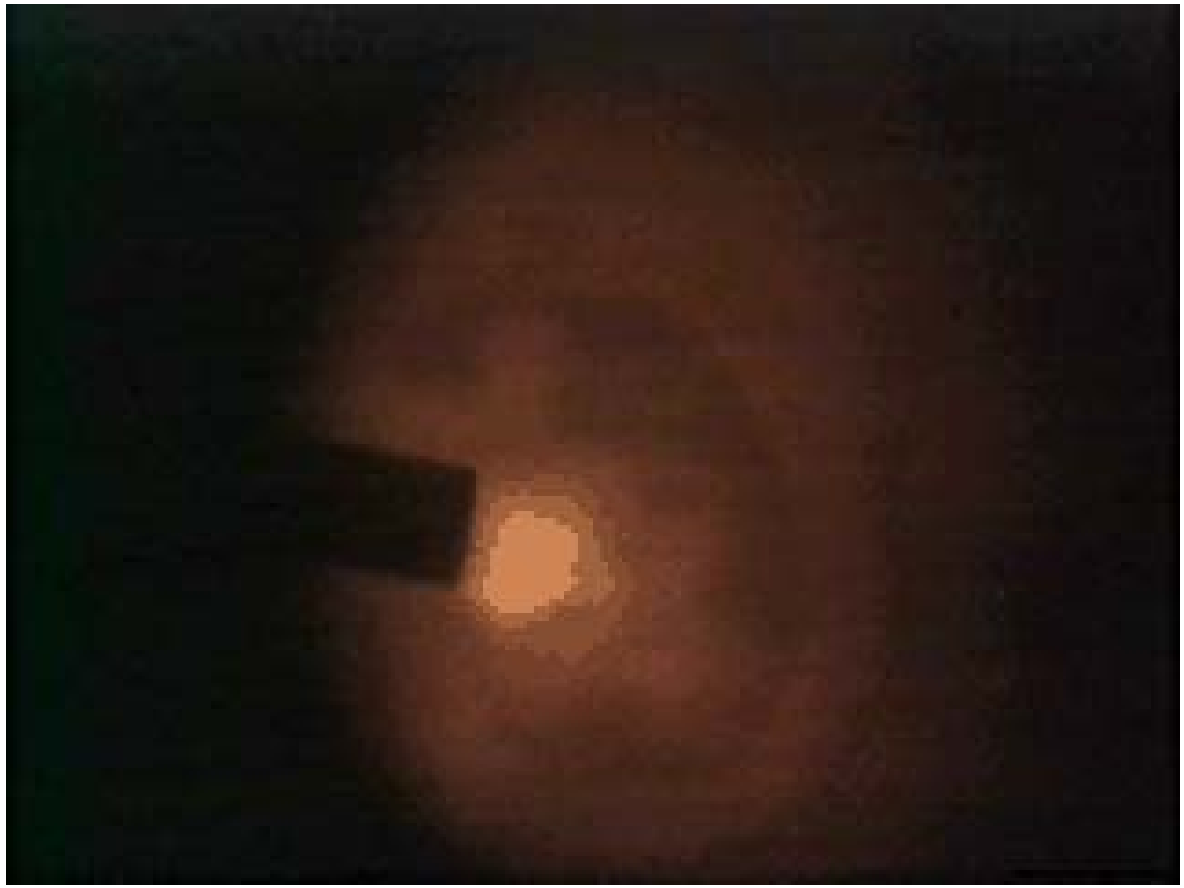
Furnace Sampling Probes

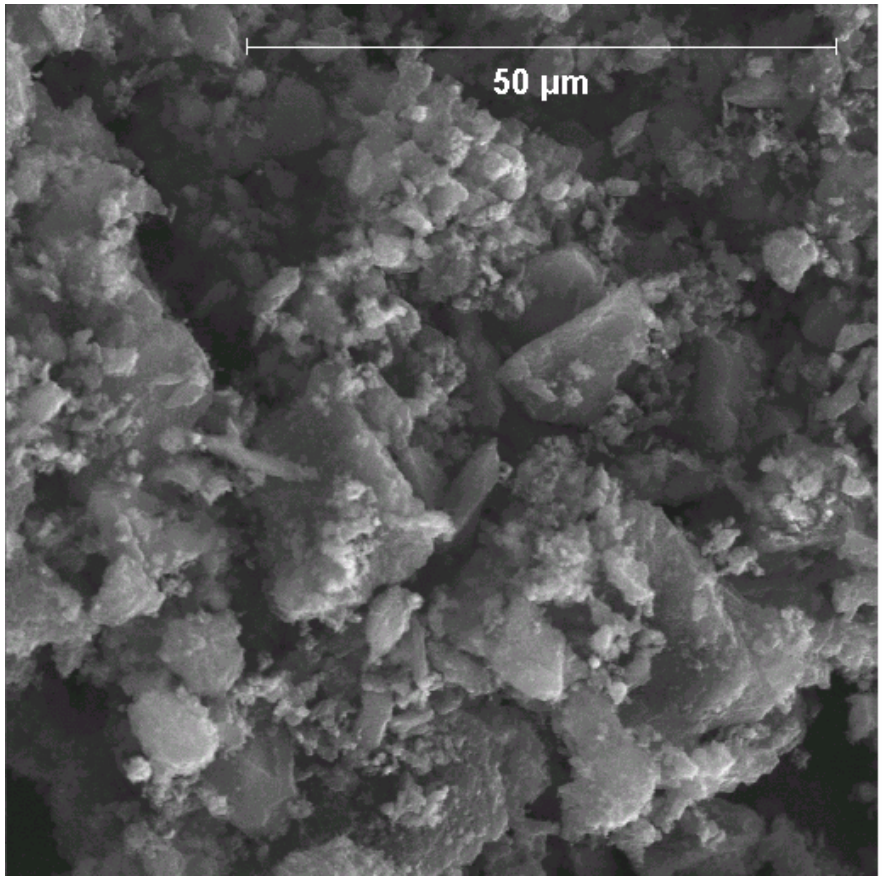


NETL Borescope Probe
View of Pulverized Coal Flame and Sampling Probes

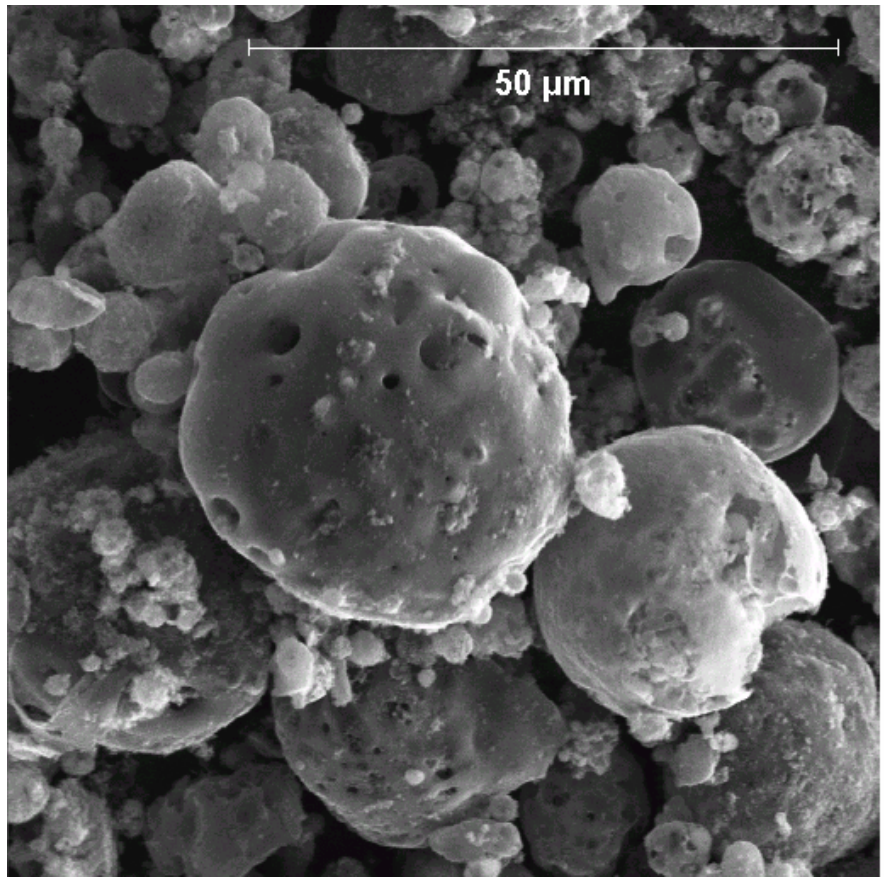


Support – Conventional HVT, gas, and particulate sampling probes … Lab-scale screening of Thief samples for Hg reactivity

Norit Darco



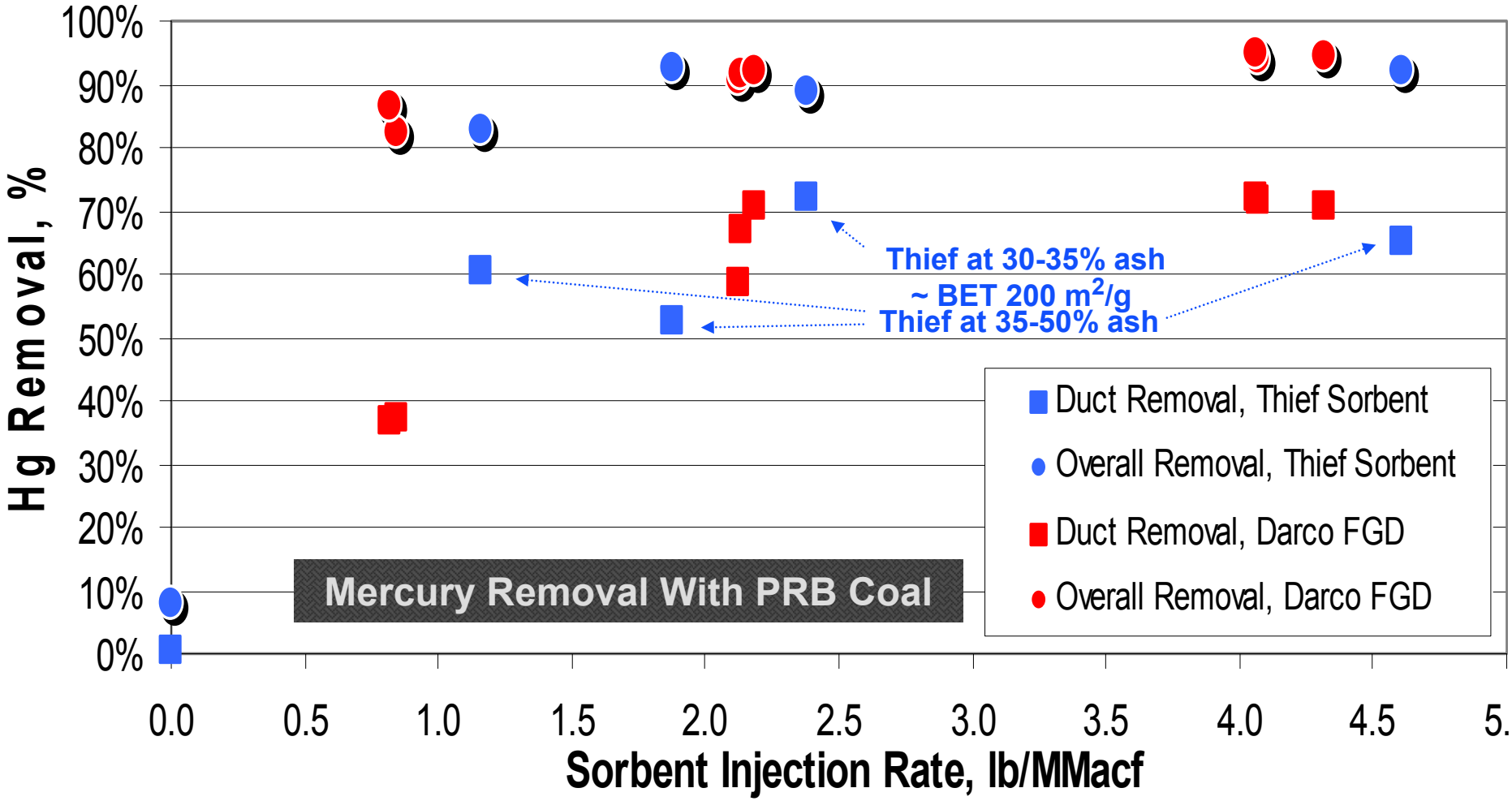
Thief Sample



Characterization - Surface area (BET), pore volume, particle size, bulk chemical anlysis, microanalysis

Mercury capacity in lab-scale screening

Mercury Removal Results - Darco FGD vs. Thief Sorbent



Baghouse 270°F **Sorbent Duct Residence Time 2.5 sec**

Example Relationship of Particle Burnout & Furnace Gas during Combustion

Semi-Combusted PRB wt% basis							
Ash	20.1	24.7	32.0	37.5	45.4	51.9	60.6
Carbon	78.2	73.7	66.6	61.1	53.4	47.0	38.4
Other (S, N, O, H)	1.7	1.6	1.5	1.4	1.2	1.1	1.0
Carbon Conversion, %	57	67	77	82	87	90	93
Furnace Gas							
lb gas per lb particle	17	24	35	44	57	69	84
(ranges during	18	25	37	46	59	70	85
combustion)	21	29	41	50	62	71	86

Support Tools – CFD modeling, in-furnace sensors (LOI, CO, temperature) and conventional sampling probes … lab-scale screening of Thief samples (for Hg reactivity) for site-specific boiler designs

Thief Process Equipment

- **Thief Process – engineering & field assembly of small components for slipstream**
  - Probe, including small boiler penetration
  - Duct work and insulation
  - Simple (e.g., double pipe) heat exchanger
  - ID Fan
  - Instrumentation and controls
  - *Optional* - baghouse/cyclone, small storage hopper, sorbent feeder … for intermediate Thief sorbent collection/storage to add flexibility

  Engineering strategy for managing a small series of heat rate penalties (in lieu of sorbent purchases) is the key driver in Thief Process
- **Thief Process**
  - Extraction of ~ 0.1 - 0.5% of furnace gas inside boiler
    - Much lower requirements than utility FGR experience or 3-5 MWe slipstreams built for field studies of flue gas cleanup technologies
    - Heat rate penalty << 0.5%

Thief Process – Thermal Heat Rate Penalty

The thermal heat rate penalty basically consists of 3 items:

- **Combustible heat loss, based on estimated heating value of Thief solids (e.g., unburned carbon loss*14,500 Btu/lb, and adjusted for H, S, etc.)**
  - Combustible heat loss includes Thief furnace gas – for example, where Thief gas contains appreciable quantities of carbon monoxide (4374 Btu/lb).
- **Sensible heat loss when cooling the extracted Thief solids & gas through the system prior to re-injection**
  - This is given by the calculated heat capacities of Thief gas composition (based on standard correlations) and estimate of Thief sorbent heat capacity
- **Additional heat losses, the most important is the *incident heat transfer* from the furnace gas (boiler) to the high-temperature Thief probe**
  - This is based on designing a probe to absorb a specified incident heat flux (Btu/hr-ft2), and surface area of probe (OD and length) inside the boiler

The latter two considerations influenced by engineering design in managing heat rate losses (e.g., tie-in with cooling water system, temperatures where extraction/re-injection occurs)

Thief Process – Parasitic Power Requirements

- **Suction (e.g., fan power) for extraction of Thief sorbent/gas from the furnace and reinjection into downstream location**
  - This is calculated based on Thief gas requirements and pressure drop through various probe(s) and piping
- **Pneumatic injection if Thief sorbent is stored and handled similar to activated carbon … if so, this is treated similar to the ACI case**
- **Pulverizer power required for make-up coal from thermal heat penalty**
  - Pulverizer power is specified on per ton coal basis, and a typical value for existing pulverizers is 22 kW-hr/ton coal
- **Parasitic power associated with circulating any heat exchanger cooling media (e.g., if a separate heat transfer system with new pumps, etc. would be purchased)**
  - Largely negligible if cooling is tied-into the power plant water system assuming existing system can handle minute changes in pressure head
    - Thief incremental cooling requirements are very small compared to the power station so that total water circulation is basically the same
    - Thief process basically diverts a minute fraction of the water flow through a system which may have slightly higher pressure drop due to the small scale of heat exchanger piping


RECYCLE

Example Heat Balance for Thief Process (at at 2 lb/MMacf) for 500 MW PRB Reference Plant

Thief Sorbent, wt% Ash	30.0	35.0	40.0	45.0
Thief Gas, lb gas per lb particle	34	42	51	59
Thief Sorbent, tons per year	796	796	796	796
Heat Rate Penalty - MMBtu/yr				
combustible heat loss	17,443	16,599	15,693	14,745
sensible heat loss	40,988	50,516	60,389	70,338
incident heat loss	15,088	16,771	18,352	19,819
sum	73,519	83,886	94,434	104,902
Coal Firing Rate - Trillion Btu/yr	37.3	37.3	37.3	37.3
heat rate penalty, %	0.22	0.26	0.29	0.32
With 70% Incident/Sensible Recovery				
heat rate penalty, % (adjusted)	0.10	0.11	0.12	0.13

Example Parasitic Power Considerations for Thief Process (at 2 lb/MMacf) for 500 MW PRB Reference Plant

Thief Sorbent, wt% Ash	30.0	35.0	40.0	45.0
Thief Slipstream Duct Work				
Thief Gas Flow, lb/hr	8936	9581	11506	13445
Duct Pipe Size, inch	12	12	14	14
Parasitic Power - Thief Gas Suction				
Thief Gas Annual kW-hr	326,989	349,388	418,398	487,932
Parasitic Power - Pulverizer Coal Make-up				
Thief Coal Make-up Flow, ton per year	5394	5593	6291	6985
Annual Incremental Pulverizer kW-hr	118,668	123,046	138,402	153,670
Parasitic Power - ID Fan Increment				
Thief Gas Estimated Power, kW-hr	52,552	54,489	61,295	68,048
Parasitic Power - Thief Total, kW-hr	498,200	526,920	618,100	709,640
Parasitic Power Requirement, %	0.014%	0.015%	0.018%	0.020%

Example Impact on Fly Ash for Thief Process (at 2 lb/MMacf) for 500 MW PRB Reference Plant

	wt% ash composition in Thief Sample				
	30.0	35.0	40.0	45.0	50.0
Incremental Increase in Fly Ash					
PRB Baseline LOI, wt%	0.2	0.2	0.2	0.2	0.2
Fly Ash Percent of Total CCB	80	80	80	80	80
Baseline Fly Ash tons/yr	94250	94250	94250	94250	94250
% Increase in Fly Ash	0.84	0.84	0.84	0.84	0.84
% LOI in Final Fly Ash	0.77	0.73	0.69	0.65	0.61

Fly Ash Characteristics or Marketability Will be Studied in the Future (e.g., Perhaps During Scale-Up)

Thief Process does not introduce "external" substance in commingled fly ash

Thief Process Optimization FY05 Plans

- **Demonstrate Integrated, Continuous Testing**
  - Bypass cyclone collection and storage
    - Improved Hg removal expected with smallest Thief particles
- **Further refine Thief Process economics model**
  - Identify sensitivity options and target R&D opportunities
- **Thief sorbent characterization and 500 lb/hr furnace mapping on PRB coal, PRB blend, lignite**
  - Test Thief samples from other combustor locations & conditions
    - Obtain experimental data to evaluate sensitivities with cost model
  - Thief furnace gas characterization to enhance mapping studies and evaluate options for gas reinjection in concert with cost model
- **Support Thief licensing and scale-up**
  - Technical issues and business plan

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